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TECHNICAL MEMORANDUMS

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

No. 648

MEASUREMENTS OF VERTICAL AIR CURRENTS IN THE ATMOSPHERE

By K. O. Lange

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By K. O. Lange

In view of the important effect of vertical air currents on flying in general, and on gliding in particular, the Research Institute of the Rhön-Rossitten Society has for the last few years been actively engaged in a systematic investigation of this problem. The committee has developed various measuring methods which now make possible accurate interpretation of vertical air currents at any desired place. The results of these investigations were immediately adopted by the gliding fraternity and formed the basis of the rapid development of altitude and distance gliding. This ready adaptation of the test data in practice meant such a vigorous prosecution of the experiments as to preclude any possibility of making available the results obtained this far to the general public. For that reason I may be permitted at this time to speak on vertical air currents in the atmosphere. From the abundance of data now available and which is ready to be published, I shall select a few examples.

Since the air itself is not visible, it became necessary to either measure the air currents only in their effects or else to make air particles visible and then to measure them. The first attempts were made with smoke and in this manner the differences between aerodynamic current and the atmospheric air on small slopes were found. But that method does not lend itself readily to larger slopes, where the smoke frays out too soon, and the only possible method, photogrammetric measurement, was beset with difficulties. The balanced pilot balloon seemed more suitable. It could be proved that the physical behavior of the floating balloon balances with sufficient accuracy

*"Ergebnisse von Messungen vertikaler Windgeschwindigkeiten in der Atmosphäre." Zeitschrift für Flugtechnik und Motorluftschiffahrt, Sept. 14, 1931, pp. 513-519. (Abbreviated report of a paper read at the 20th general membership meeting of the W.G.L. in Kiel, 1931.)

the air particles displaced by it. For instance, the balloon, its internal excess pressure being negligibly small, is in balance at any altitude; the sun's rays heat the balloon but very little because of the permeability of the thin rubber skin, hence its rise in still air is very small. The balloons were trigonometrically measured over a 1 to 2 kilometer base by double-sight method with balloon theodolite every 10 or 15 seconds, and the paths plotted.

A number of such surveys were conducted over the Kurische Haff, in the shelter of the Rossitten dunes. It was found that lee-eddies and counter-eddies form on the obstacles only to break away periodically and, becoming larger, to superpose themselves on the general translatory motion of the wind. In this manner wavelike streamlines are produced which, by about 10 m/s* wind velocity, create ascending and descending currents up to 4 m/s in the lower air strata. Figure 1 shows such wavy lines, Figure 2, the originally stationary eddies, coming to light as the translatory motion disappears. Comparisons with temperature and wind records at other observation points show this up-and-down surging of the air, due to ground obstacles and recurring on an average of 2 m/s velocity in periods of the order of magnitude of 10 minutes - not to be merely confined to the local conditions at Rossitten but rather to be a frequent occurrence elsewhere whenever the wind blows over flat terrain with low obstacles. The "taches d'huile," i.e., the strips of perfectly calm water occasionally observed, are readily explained by the lifting off of the air current lines from the water by such undulatory motion.

The balloon experiments in the Rhön and in Darmstadt show the dependence of the vertical air current on the vertical temperature distribution, as theoretically expected: formation and amplification, respectively, by stable and unstable stratification, damping by small temperature gradients and repression by inversions. The paths of the balloons in the Rhön show that, by stable stratification, the streamlines on an average adapt themselves to the terrain; there occur the well-known upward or ascending air currents (topographic winds) which are directly forced by the terrain and whose magnitude and extent in height are given by the temperature distribution, by the grade of the slope and the wind velocity. By superadiabatic temperature gradients, however, the air masses, without discernible start, suddenly shoot up from the ground to great heights. The phenomenon can be explained

* m X 3.28083 = ft.

by sudden, aperiodic overthrow, through some arbitrary small impetus, of the overheated and consequently unstable air strata. Figure 3 shows a balloon over the Rhön by labile temperature distribution. For 8 minutes it is carried along the slope, then suddenly climbs to 700 m at the rate of 2 m/s. That such vertical currents assume dimensions which can become obstructive and dangerous to flying is readily apparent in Figure 4. The balloon, released on the ground, shoots by a horizontal wind velocity of 6 m/s to a height of more than 1000 m at a maximum rate of 5 m/s. And such cases are not at all rare; neither are they confined to hilly or mountainous country, but occur over flat country as well.

In order to get away from the immediate ground proximity, with its uncontrollable currents, the R.R.G. has conducted within the past year a series of experiments in which the balloon was released by airplane from greater heights. Thus, Figure 5 shows a number of them over the Darmstadt airport. In the early morning hours the radiation inversion still hovers over the ground; the higher strata indicate a temperature decrease of only $\frac{1}{2}^{\circ}$/100 m, hence the stratification is stable. During this time all balloon paths show, without substantial vertical velocities, slight inversion waves or hugging to the gradually rising ground. By 11:30 o'clock the balloon is completely outside of these bounds. The air stratification has become labile from ground level up to 1400 m, with a heavy inversion at 1400 m. Over the same terrain, which in the morning was without vertical air currents, the air now shoots upward at 11:30 a.m. for a distance of more than 900 m and at a rate of 3 m/s, until the ascending air smothers at the inversion.

Another very clear picture of such up-and-down whirling air masses is given in Figure 6. There was a slight southwest breeze; the sun shone bright on the ground. Released at 500 m, the balloon first oscillated between 500 and 800 m with vertical velocities of over 1 m/s, then rose at the end of its course from 500 to 1100 m at a rate of 2 m/s and dropped at the same point at the rate of 3 m/s. It probably was caused by a whirlwind, such as occur more often in our latitudes than is generally surmised, because they do not become visible. The abrupt change from 5 m/s in vertical velocity would prove disastrous to an airplane trying to land in tail-high attitude. These vertical currents are not restricted to slightly windy days on which individual localities may become hotter than oth-

ers because of lack of ventilation, but are equally encountered on very windy days, when, of course, the ascending and the descending currents are locally or temporarily farther apart.

Temperature inversions resist the vertical air exchange and generally retard the vertical velocities completely. On the other hand, inversions themselves can set up vertical currents, namely, when the temperature reversal is accompanied by a sudden change in wind direction. Then aerial billows are formed on the boundary surface. The balloon, as seen in Figure 7, was in an inversion at about 1200 m over the mountain tops; it shows waves of over 3 km length with a maximum vertical velocity of 1 m/s which, however, is not solely caused by the undulatory motion as such, but also by the elevation of the inversion. The vertical velocities in such billows are usually low and can impair flying only when happening to be just below the ceiling of the airplane. And even then the density jump of the inversion will have a more decisive effect than the low vertical velocities.

Of the vertical velocities treated so far, those formed by unstable temperature stratification are the most clearly marked. They become of special significance for gliding when leading to the formation of clouds and then their appearance becomes so marked that the glider pilot can spot them immediately. For this reason the institute paid particular attention to the up-current conditions under cumulus clouds.

The effects of the vertical currents were measured in light airplanes, primarily of the 35 hp GMG type, whose minimum sinking speed with propeller locked is 2.3 m/s. This was checked by numerous test flights during the early morning hours and is practically constant within a considerable speed range - 60 km to 80 km/hr.* These vertical velocity measurements were supplemented by glide tests with locked propeller and constant dynamic pressure at certain designated points. The sinking speeds were read by means of two special meteorographs; their difference with the normal sinking speeds yields the vertical movements of the atmosphere.

Aside from the easily eliminated slight air density effect on the sinking speed, acceleration effects also

*km X .62317 = mi.

cause errors in the readings which, however, still permit of an accuracy of $\frac{1}{2}$ m/s. The amount of inertia of the pressure recording for such cases is not known as yet, but it appears after several comparable measurements of the airplane by double sight method, that the actual vertical velocities are greater than those we found. The rate of climb was interpreted in similar fashion with, of course, less accuracy because of the engine effect.

Nearly 200 such test flights were made and interpreted during the past year. Judging from the data worked up so far, the air currents of the cumulus clouds present a picture as follows: Because of the heating of the ground and the subsequent exchange at lower heights, an adiabatic temperature drop is formed, and in the lowest few hundred meters the temperature drop is even highly superadiabatic. Ground obstacles or local overheating cause overthrows of this unstable air layer which, as previously pointed out, may bring about vertical velocities of the order of magnitude of 5 m/s. Due to cooling of the air rising from lower heights which, while rising, does not change its temperature with respect to the surrounding air - because the gradient also is $1^\circ/100$ m - the relative humidity rises up to condensation. The effect of the freed heat of condensation is that the air no longer cools off at the rate of $1^\circ/100$ m, but at a much lower rate, according to the humidity adiabatic. The result is a static lift, which enhances the up-current, and for such a time until the temperature outside of the cloud air reestablishes density equilibrium by inversions or by temperature gradients which are smaller than the humid adiabatic gradient. Therefore, when condensation sets in, the occurrence of strong vertical currents is no longer bound to a $1^\circ/100$ m temperature decrease. Even a gradient greater than the humidity adiabatic suffices; the air must be in humid labile layers. But because of its motion energy the cloud air pushes beyond the position of equilibrium, just like a free balloon during ascent. The temperature in the cloud is then lower than that of the surroundings - a fact frequently confirmed by airplane measurements during climb. After the energy of the upward motion is dissipated by friction and drift, the cloud air, in order to reestablish equilibrium, falls back, forming a descending current. This stage of the down-wind under the cumulus is characterized by the stringy aspect of the cloud, and experienced glider pilots know well enough to avoid flying into such "down-wind cumuli." Figure 8 shows the altitude-time

curve and the temperature-time curve of a test flight on a becalmed summer day. At the time of the flight the cumulus was in its stage of fullest development. Already at 200 m the airplane is pulled upward at a 3 m/s greater rate than its normal rate of climb; from 800 m on up to the cloud base the up-current averaged 4 m/s. To prevent being pulled into the cumulus with the light airplane, which in addition was not equipped for cloud flying, the pilot flew alongside the cloud. Here the uprush slackens quickly; even over the peak of some adjacent cumuli the rate-of-climb curve is wholly normal. The descent is, so to say, a reflected image of the ascent. At the side of the cloud there was little vertical motion, beneath it we noticed up-winds up to 2.5 m/s; in fact, so great that the airplane with locked propeller not only did not lose but even gained some altitude. The temperature distribution during this flight may be seen in Figure 9. Up to 1800 m the stratification is dry adiabatic, above it the gradient becomes small. In the lower range of the cloud air we encountered higher temperature during the ascent, indicative of local overheating as the reason of the subsequent overthrow. The air whirls upward; condensation, and thereby a new heat supply sets in at 1600 m, which still allows the ascending air masses to penetrate into the stable air strata. The equilibrium position is still low because of the small gradient, thus making the stage of decay of the cumulus a speedy one. The descent of the test flight now shows only 2.5 m/s up-wind against 3 and 4 m/s during the ascent. Figure 9 presents, aside from the temperature distribution, a chart of the distribution of the vertical velocities with the height during this flight.

During the test flights the location of the airplane with respect to the cloud was determined by the record of the pilot, and in many cases both flight path and cloud were measured from the ground. It was found that instead of a uniform up-wind found beneath the cloud, the vertical velocities in the ambit of the cloud are subject to severe fluctuations. This was wholly to be expected, because for one thing, the condensation is everything but uniform, and for the other, the turbulence disrupts such a uniform exchange. Glider tests at Darmstadt revealed that toward evening when the atmosphere attains a certain calm, extensive steady up-wind zones take the place of the irregular up and down currents which, for instance, made it possible at various times to climb the glider from 400 m to 1000 m and even to 1400 m in a perfectly clear sky and gentle breeze.

In certain contrast to the vertical movements on the fair-weather cumuli, which quickly spring up and just as quickly disappear, are the vertical movements in stormy weather. It was established that constant up-currents prevail at the area in front of the storm which, for instance, made it possible several times to soar an airplane with locked propeller for a quarter of an hour and longer without losing altitude. The most striking illustration is the 265-kilometer soaring flight of the "Fafnir" sailplane of the R.R.G. from Munich into the Erz mountains, wherein Groenhoff sailed for over six hours in the up-current of a storm at altitudes ranging from 200 to 2500 m. Greater yet than the hitherto investigated vertical velocities are those within clouds according to theoretical deliberations based on the humid instability and on isolated test results. One case in point is the flight of a Junkers A.20 in a storm cloud at the weather forecasting station, Darmstadt, in which the airplane went into a climb in spite of idling engine and 200 km/h gliding speed. As seen in Figure 10, the sinking speed of the A.20 is approximately 10 m/s for this flight, the points of maximum up-current induce a climb of 2 m/s, so that a cloud up-wind of up to 12 m/s was recorded. The Research Institute is actively engaged at present in a systematic investigation of the up-wind within clouds.

To summarize, the experiments with balloons, sailplanes and light airplanes conducted thus far, reveal the vertical velocities of the air to be primarily dependent on the vertical temperature distribution. Stable stratifications result in up-and-down currents forced by the contour of the ground, which are readily recognized in flight and, if need be, may be avoided. The generation of eddies on obstacles sets up vertical movements even over level ground, which already are more disagreeable because of their irregularity. An adiabatic temperature distribution produces irregular up and down currents which extend from the ground to great heights and frequently attain a velocity of 5 m/s. These air currents are dangerous to flying because they form abrupt local and periodic alternations of ascent and descent of the surrounding air and their effect on an airplane is cumulative.

They almost always appear on cloudless days as well as on days when the sky is clouded with cumuli and are difficult for the pilot to distinguish. They become critical when they bring the airplane into a stall during take-off or landing. In view of our present-day knowledge of

vertical velocities of the air an up-to-date, unobjectionable airport should be so located that local overheating, i.e., the impetus to severe vertical movements, are precluded as much as possible. Ground obstacles should be some distance away from the landing area, not simply because of the up and the down currents which they directly set up, but also because of their tendency to generate eddies and to overthrow labile air masses. Lastly, the place should have a large area for flattening and during landing so that take-offs and landings may be made without putting the airplane into a stall. Vertical movements of more than 12 m/s have been recorded on the inside of cumulus clouds, so that every flyer of commercial airplanes should be warned outright against entering even an apparently perfectly harmless cumulus cloud.

Discussion

Dr. Koppe: During the war, as well as in commercial aviation, it frequently happened that severe squalls lifted the passengers off their seats and even threw them out. The destruction of airplanes by squalls has just recently been commented upon. So long as the fact that a squall was actually the cause is not absolutely ascertained, the dissemination of such information to the public should be made with caution, in the interest of aviation. Further research of such squalls, as well as of the accidents caused by them, is extremely important.

Mr. Langer: To supplement Dr. Lange's paper, I shall show several photographs taken during the flow investigations at Göttingen, on mountain models. A particularly interesting feature of a mountain model with pointed dome, is that the flow, made visible by fine smoke threads, breaks away at the dome-shaped summit and that the up-wind zone still extends behind it for a way. On the model with flat dome the flow above the dome is horizontal.

Dr. Thalau: The arguments of Dr. Lange are of very particular significance to airplane designers, because the up-currents, so useful for gliding activities, are not looked upon with much favor by the airplane designer. In form of vertical and horizontal squalls, they may stress the wings and control surfaces of an airplane more than the intentional control maneuvers by the pilot. This case

happens so much quicker as the ratio of horizontal to landing speed is greater.

Unfortunately, it took several bad accidents, particularly last year, to show that the unintentional stresses due to such atmospheric effects must be given special attention; the German aircraft committee then undertook its investigation on "design loads." But in order to be able to rationally calculate the new load cases, there is still much research to be done on the structure of squalls, their extent in the air, their velocity in the different directions and on the velocity gradient. It is urgently recommended that the investigations of the R.R.G. be pressed vigorously and moreover, be extended to include the still open questions with respect to the concerns of the airplane designer.

Dr. Lange: The extensions of the measurements of the R.R.G., as suggested by Dr. Thalau, are already under way. The program includes direct stress measurements due to the air structure by means of accelerometers, as well as by flight-path readings, dynamic-pressure records and interpretation of gliding flights, so as to give a picture of the extent and velocity distribution of squalls. Because it is necessary to first develop our test methods, as well as to construct our test instruments, the data at present are not quite as comprehensive as the airplane designer would wish them to be.

Translation by J. Vanier,
National Advisory Committee
for Aeronautics.

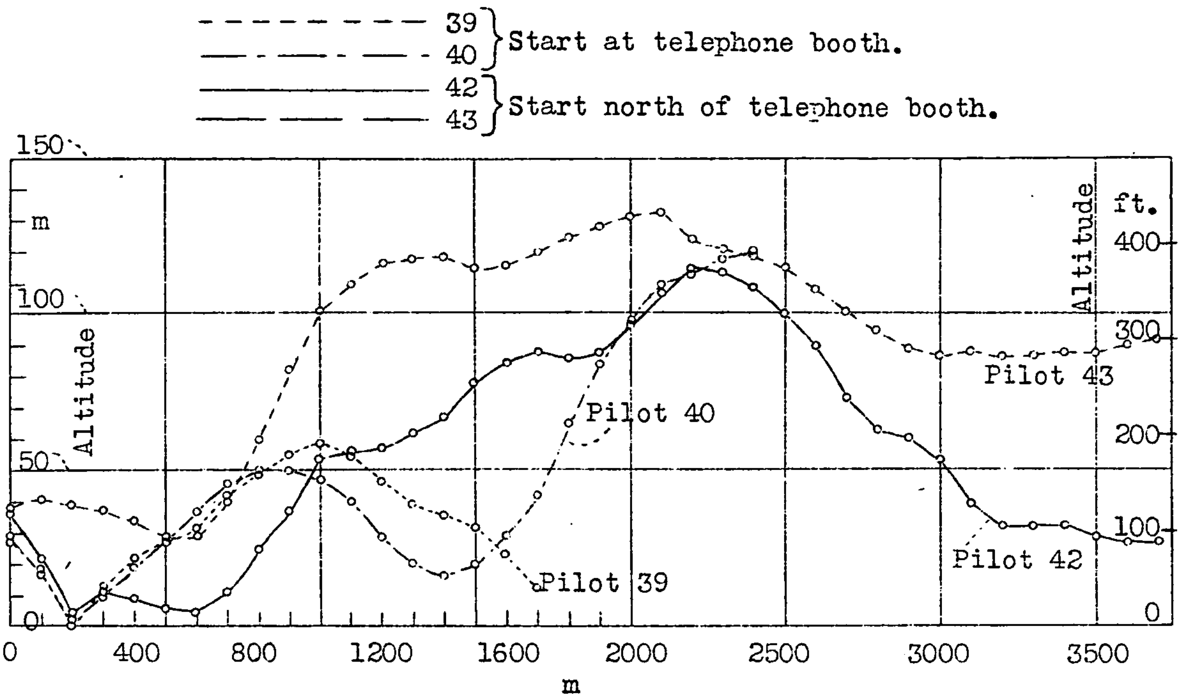


Fig.1 Streamlines of the air over the Haff in the shelter of the Rossitter dunes.

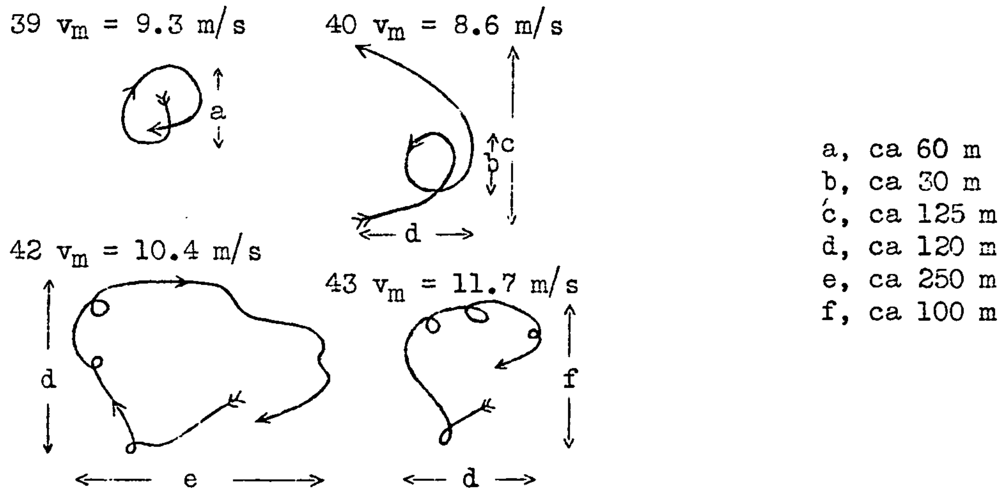


Fig.2 Eddying flow within the translatory motion of the wind in the lee of an obstacle.

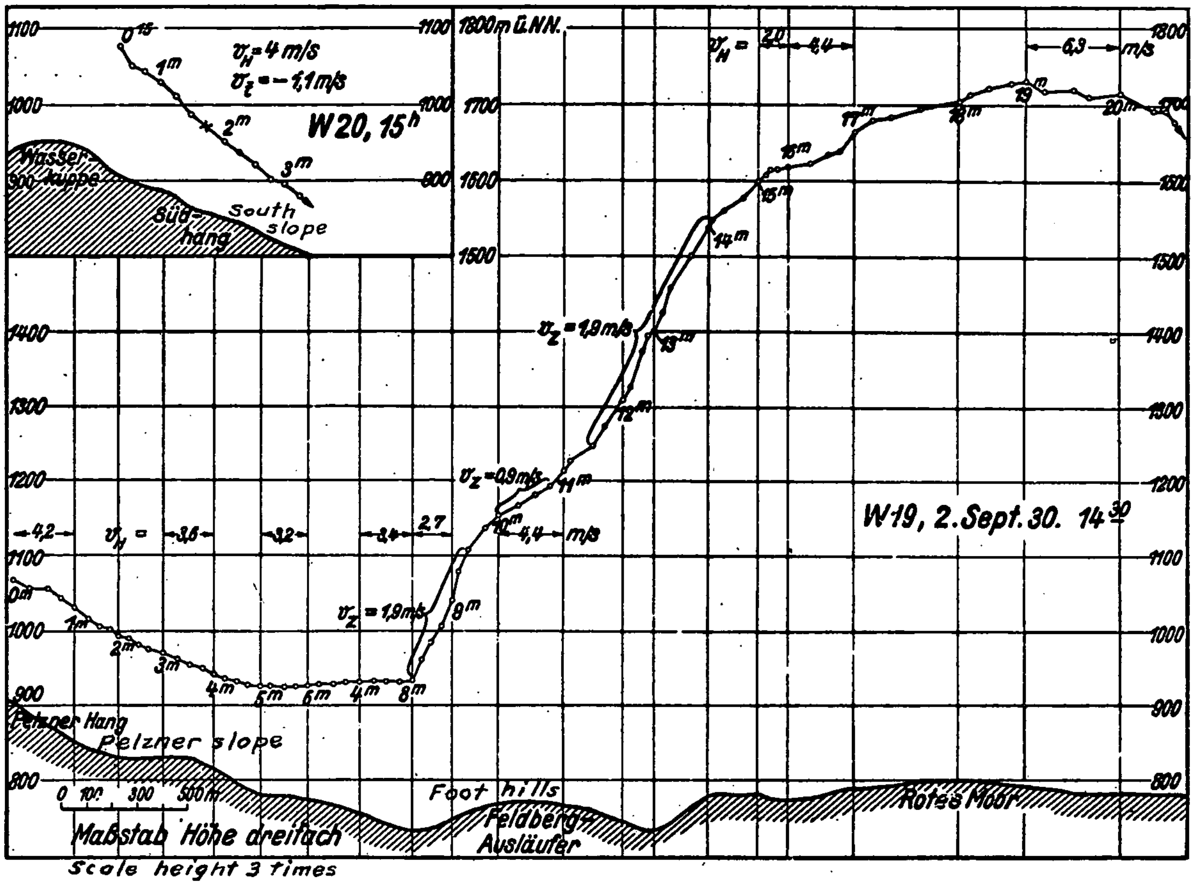


Fig. 3 Course of balloon over the Rhön, unstable temperature layers.

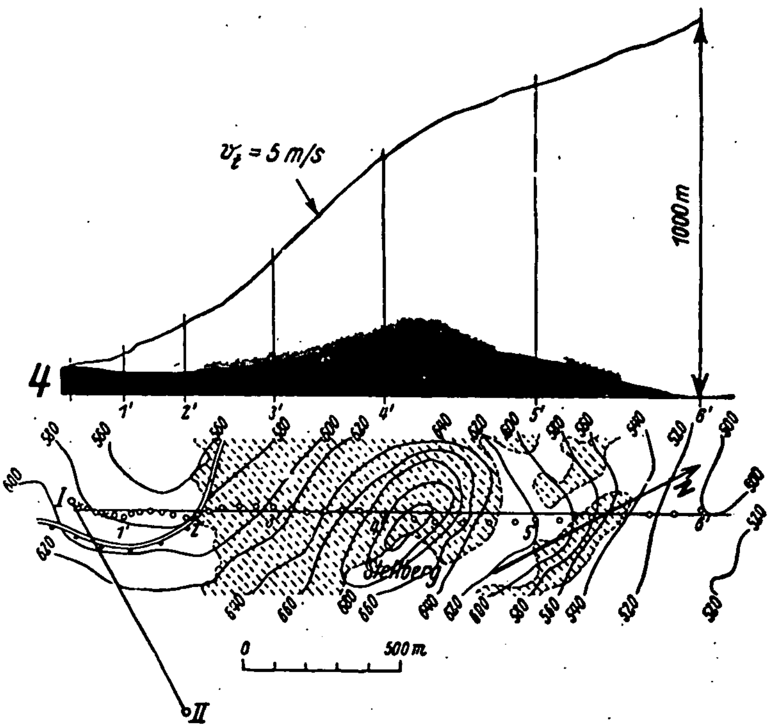


Fig. 4
Course of
a balloon
in the Rhön.

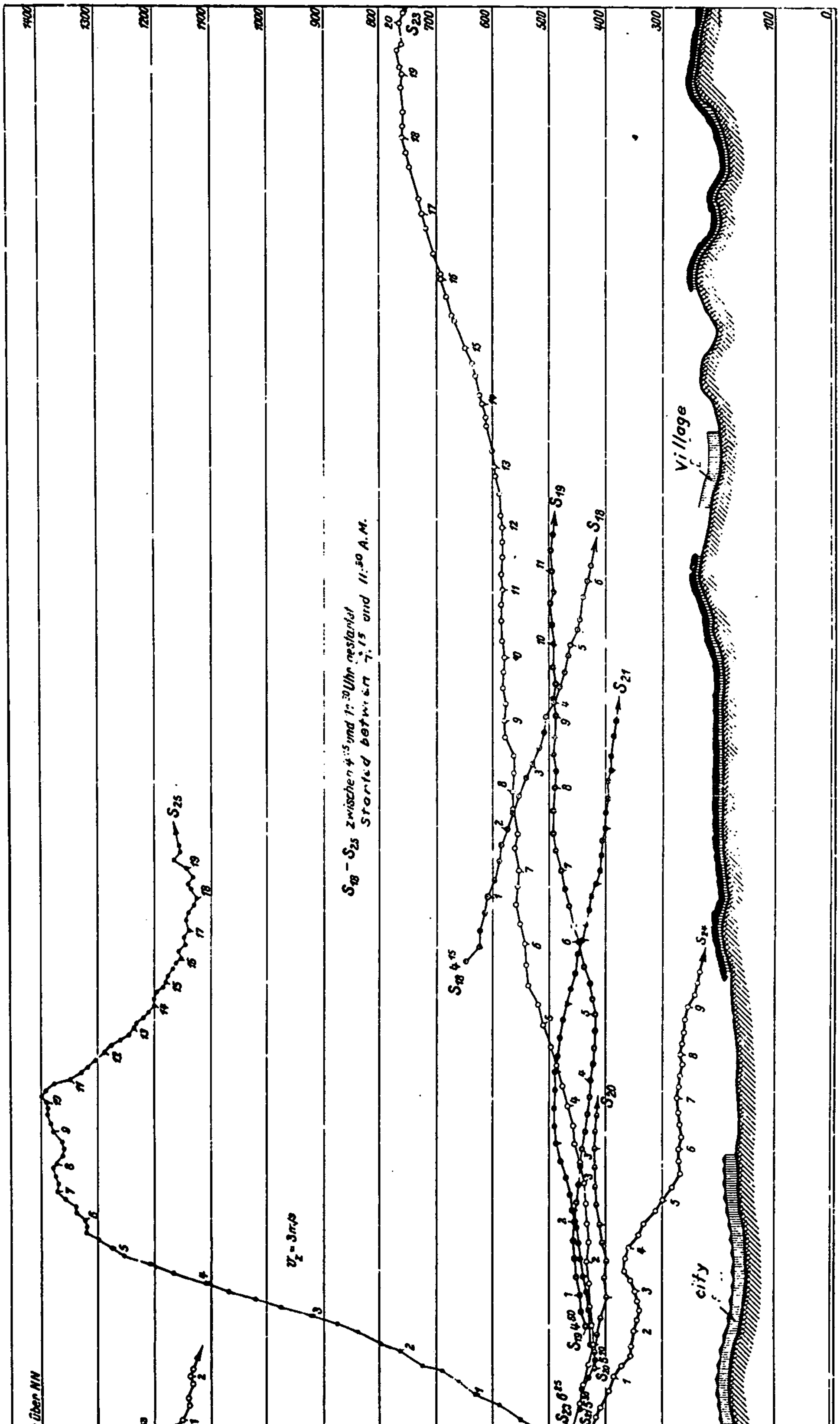


Fig.5 Balloons at early morning, and around noon.

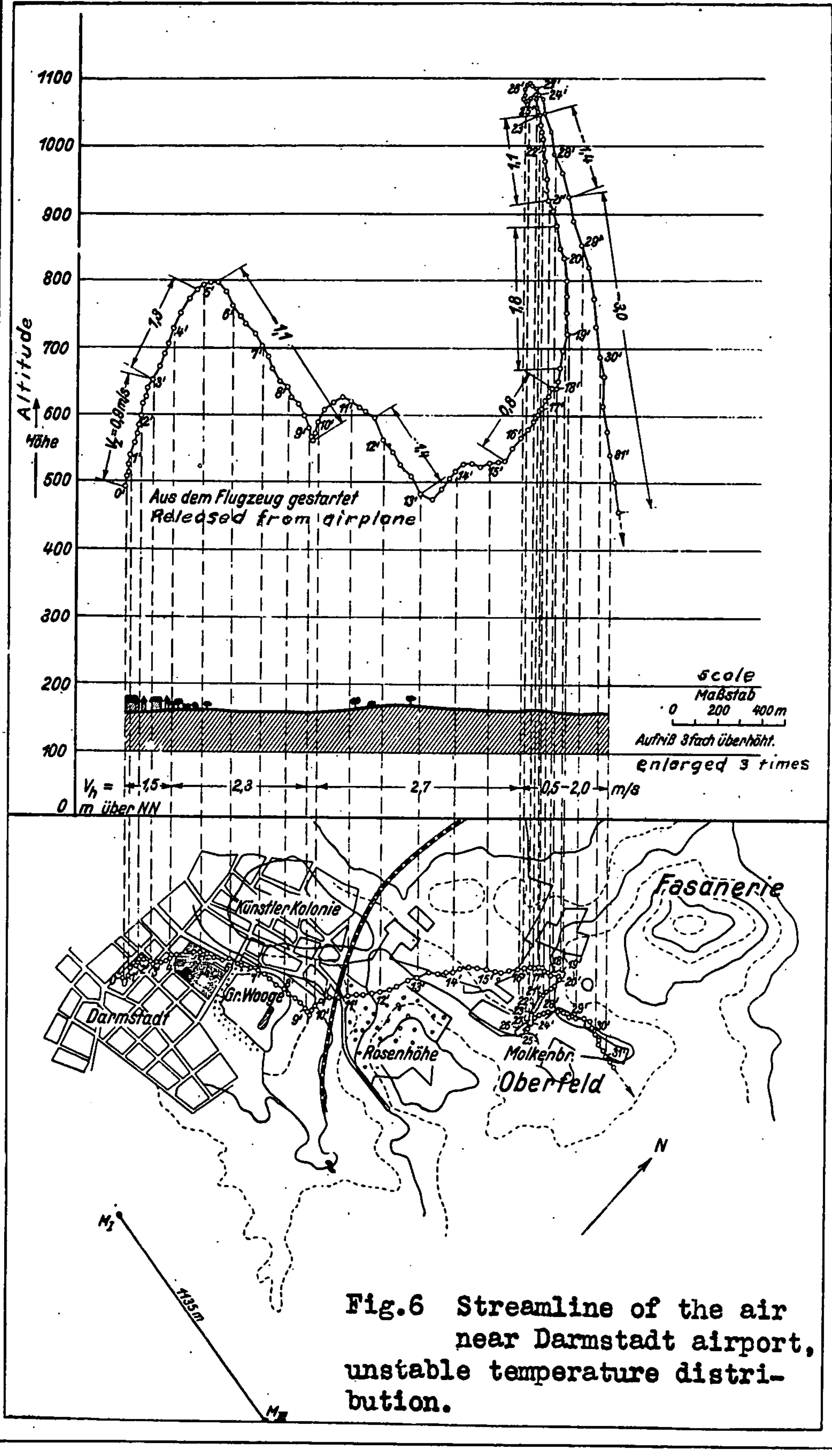


Fig.6 Streamline of the air near Darmstadt airport, unstable temperature distribution.

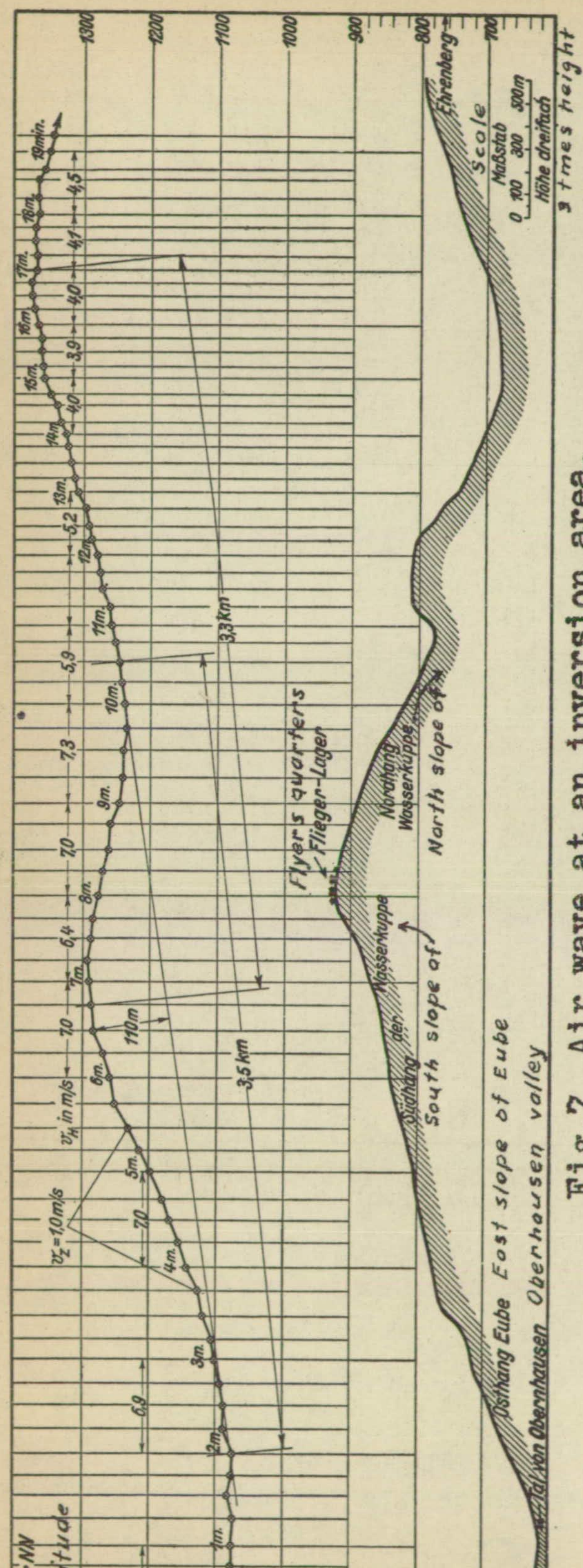
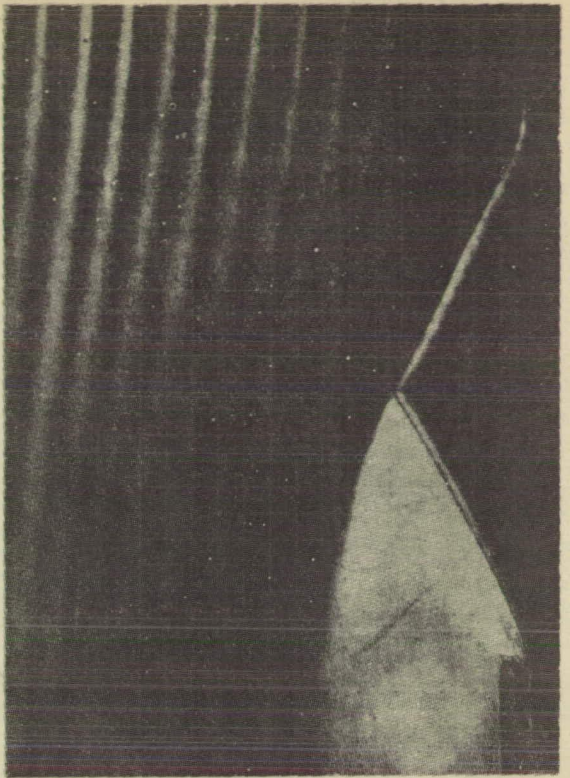


Fig.7 Air wave at an inversion area.

Fig.11 Flow around a mountain model with dome-shaped summit. July 1, 1929. 4:45 o'clock. ⟶



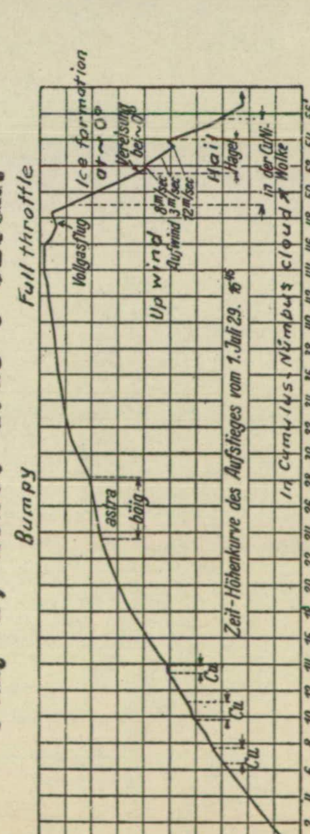


Fig.10 Time-altitude curve of flight in Junkers A-20 in a storm cloud. July 1, 1929. 4:45 P.M.

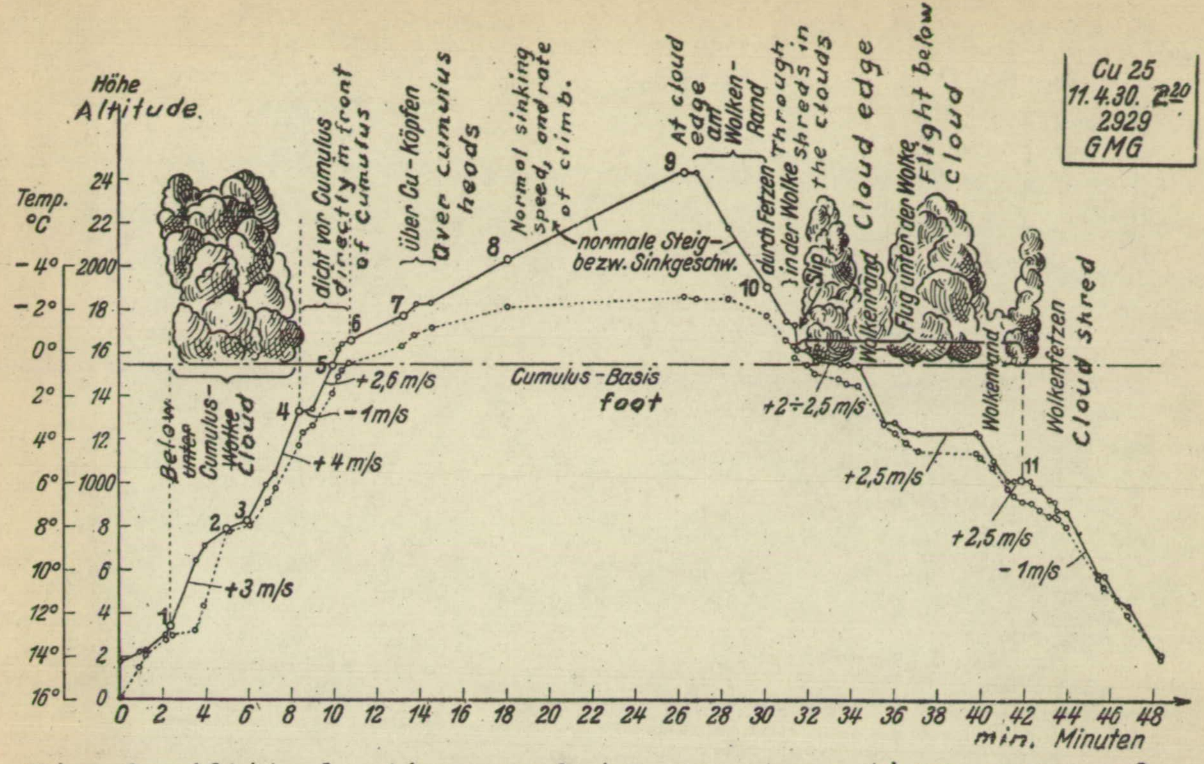
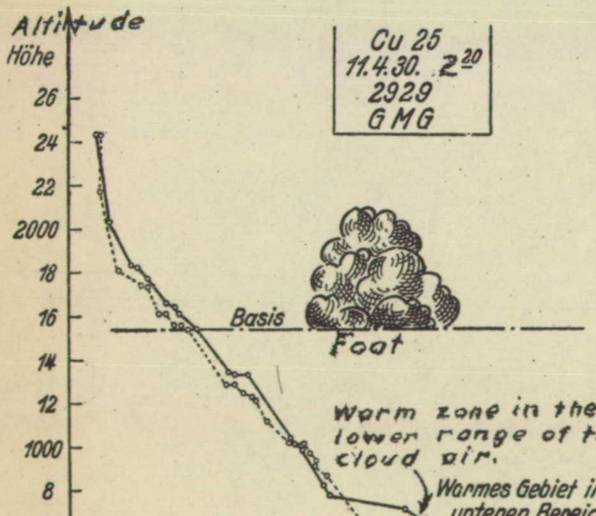


Fig. 8 Altitude-time and temperature-time curve of test flight to determine the vertical velocity beneath a Cumulus cloud.



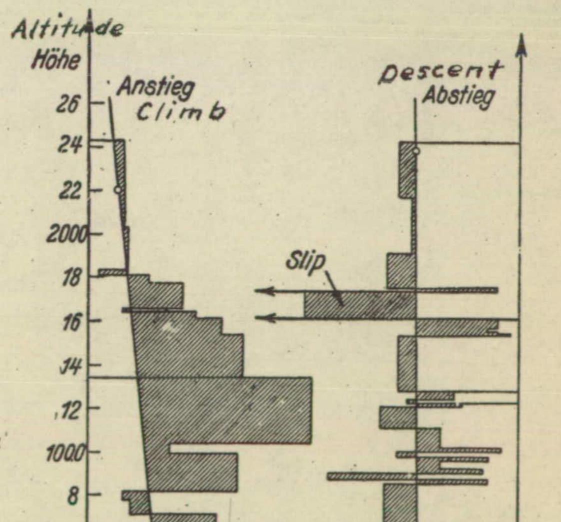


Fig. 9 Temperature-altitude and altitude-vertical velocity curve of flight of Fig. 8.